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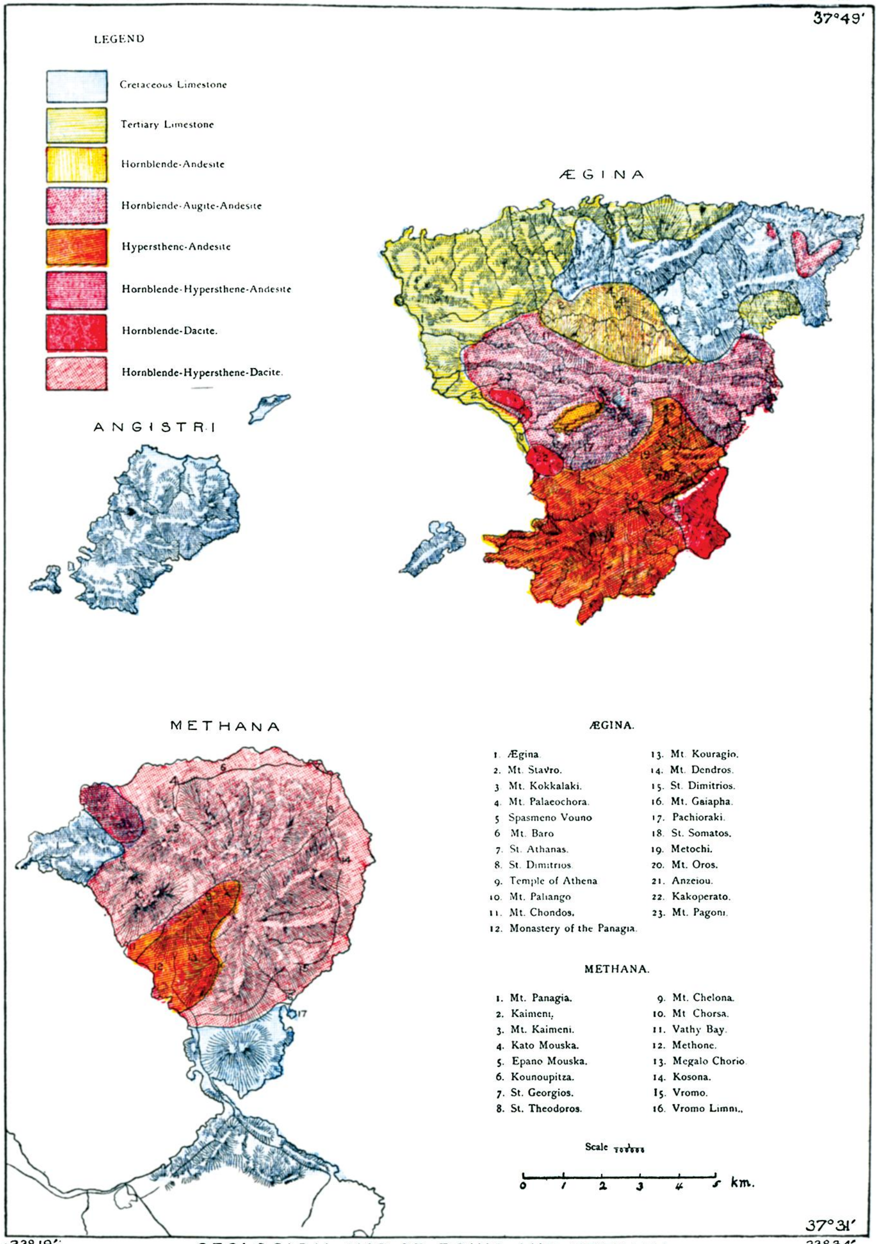
JOUR. GEOL. VOL. II, 1894. PLATE III



ÆGINA.

1. Ægina.
2. Mt. Stavro.
3. Mt. Kokkalaki.
4. Mt. Palaeochora.
5. Spasmeno Vouno
6. Mt. Baro
7. St. Athanas.
8. St. Dimitrios.
9. Temple of Athena
10. Mt. Paliango
11. Mt. Chondos.
12. Monastery of the Panagia.
13. Mt. Kouragio.
14. Mt. Dendros.
15. St. Dimitrios.
16. Mt. Gaiapha.
17. Pachioraki.
18. St. Somatos.
19. Metochi.
20. Mt. Oros.
21. Anzeiou.
22. Kakoperato.
23. Mt. Pagoni.

METHANA.

1. Mt. Panagia.
2. Kaimeni,
3. Mt. Kaimeni.
4. Kato Mouska.
5. Epano Mouska.
6. Kounoupitza.
7. St. Georgios.
8. St. Theodoros.
9. Mt. Chelona.
10. Mt Chorsa.
11. Vathy Bay.
12. Methone.
13. Megalo Chorio.
14. Kosona.
15. Vromo.
16. Vromo Limni.,

Scale $\frac{1}{100000}$

0 1 2 3 4 5 km.

GEOLOGICAL MAP OF ÆGINA AND METHANA
BY HENRY S. WASHINGTON.

A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.

PART I.

Introduction.

DURING several visits to Greece the volcanic island of Ægina and promontory of Methana, which are plainly seen from the Acropolis of Athens, had always presented themselves as a promising field for petrographical investigation. The attractions they held out were enhanced by the fact that since 1867 they have been unvisited, or at least undescribed by a geologist; and as the progress of petrography since that date has been so great, they seemed capable of furnishing much new and perhaps interesting material. An opportunity presented itself in March, 1893, when I was able to devote a week to Ægina and Methana together, with part of a day at Poros. This too short visit was supplemented by a second week spent at the same localities in March, 1894. A day was also devoted to visiting and collecting at Kolautziki, near Kalamaki on the Athens-Corinth Railroad, and at the neighboring valley of Sousaki, with its interesting mofetti. The collections made on these two excursions, which form the basis of this paper, are quite complete and typical of the various eruptive rocks of the region; the total number of hand specimens amounting to 122.

The predominantly petrographical character of the paper here given will explain the very cursory and imperfect way in which many of the geological and stratigraphical features are treated, only such a short sketch and description being given a may be necessary to give the reader a sufficient idea of the general structure.

For the accompanying geological map there was used as a basis the British Admiralty Chart No. 1514, which in Ægina is very accurate in its delineation of the orographical and topographical features, but leaves more to be desired in the case of Methana. Some names have been altered and some new ones inserted, in accordance with my own notes, but otherwise the map is essentially the same as the original. It is much to be regretted that the construction of a complete and accurate geological map was out of the question, and in its geological features the present map does not claim any great accuracy, and must be regarded as merely an attempt to give the reader a general idea of the relations of the various rock masses, whose boundaries are in many cases more or less hypothetical. Though the roads are bad, traveling (on horseback) is easy, the people are kind and hospitable, and the only impediments are the extreme roughness of the accommodations and the absolute necessity of some acquaintance with the modern Greek language, an accomplishment not very difficult to learn. It must be added that the hypsometric figures, which are expressed in metres, are taken from the Admiralty Chart and from the work of Reiss and Stübel, to be mentioned later.

In conclusion, I must express my warmest thanks to Professor Zirkel for his very kind advice, to Dr. H. Lenk of the University of Leipzig for making the specific gravity determinations for me, and to Dr. A. Röhrig of Leipzig for the care and zeal he showed in making the chemical analyses.

Literature.—A short sketch of the previous geological descriptions of the region must be given, as they will be often referred to. The writings of the travelers prior to 1800 I have not consulted, since their descriptions, while matters of interest, would be of no petrographical value. Among the earliest in this century was Dodwell,[1] who spent a day at the Acropolis of Methana, recognized the volcanic origin of the peninsula, and recommends it to future geologists for investigation. The first really geological investigation was that made by MM. Boblaye and Virlet[2] during the French expedition to the Morea in 1832. Partly owing to its early date their geological descriptions are unsatisfactory, and from several indications, such as speaking of a lava stream at Kaimeni on Methana only as reported by M. de Vaudrimey, they seem not to have explored the region very thoroughly; and their geological sections, both of Ægina and Methana, show many signs of a too free use of the imagination and of the imperfect methods of observation of the time.[1] They express the view (p. 240) that the "trachyte" masses have been raised (*soulevées*) "in a solid or scarcely pasty condition," preceded by the deposition of Tertiary beds. Their descriptions of the various rocks are naturally quite superficial, and in many cases not in accordance with subsequent observations, as when they unite the widely different rocks of Palæochora, Mt. Chondos, and Mt. Oros under one group of "*Trachyte bleu porphyroïde*" (p. 252), and state that the "Domite" (the light gray compact hornblende-andesite of Mt. Stavro) owes its character to a discoloration of the blue trachyte (p. 254). In accordance with L. von Buch's theory of Craters of Elevation they attribute this origin to the Spasmeno Vouno, and in part to Methana.

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[1] DODWELL: Tour Through Greece. London, 1819. II., pp. 281, 284.

[2] Expéd. Scient. de Morée. Sect. des Sci. Physiques. Paris, 1834. Tome II., 2me Part. Géol. et Miner. par Boblaye et Virlet, pp. 239–258 and 364–370. Atlas, 1re Série, Pl. I., III., V., 2me Sér., Pl. IV., V. Referred to as "B. & V."

The next geographical traveler was Fiedler,[2] who confined his observations in Ægina to those made on a trip to the temple ruins from the harbor, and at Methana to those made during a sail round the promontory. In the former he devoted his attention chiefly to the clays occurring on the island, though he gives a good description with an illustration (Pl. III.) of Spasmeno Vouno. In Methana he describes one or two of the hot springs, speaks of the Kaimeni stream, placing the crater whence it flowed to the north of it, as he says it is now covered by the sea, and describes the Mt. Panagia, where he states that serpentine occurs. Russigger's account[3] I was unfortunately unable to consult, and the description of Curtius,[4] whose work is largely archæological, is chiefly taken, as far as the geology is concerned, from the writers just quoted.

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[1] Cf. PHILIPPSON, Der Peloponnes., p. 5, who severely criticises their work.

[2] Reise durch Griechenland. Leipzig, 1840. I., pp. 256–278, II., pp. 541–552.

[3] Reisen in Europa, Asien und Afrika. Stuttgart, 1843 and 1848, I., p. 79, IV., pp. 246–251.

[4] Peloponnesos. Gotha, 1851. I., pp. 40–42, II., pp. 438–443.

It was not till 1866 that the region was again visited by geologists, but in this year Fouqué, as well as Reiss and Stübel, on their return from study of the Santorin eruption, examined the localities. Fouqué's account of Methana[1] is short, but he gives an excellent description of the Kaimeni eruptive centre, whose crater he was the first to discover, and which he identified as the site of the eruption mentioned by Strabo, Pausanias, and Ovid.

Reiss and Stübel[2] spent a day on Ægina, going from the harbor to the temple, thence along the eastern slope of the East Ridge to the summit of Mt. Oros, and thence to Perdika; and a little longer time on Methana, of which they explored the northwestern part, including Kaimeni and Mt. Chelona. Their account is very readable, their descriptions, as far as they go, very good, and the conclusions they draw from their observations in general, just. A short petrographical description of the rocks collected by them is given by v. Fritsch, which, being based almost entirely on a megascopical examination, is necessarily imperfect and unsatisfactory. They also give a geological map, which, however, does not go into details, and which is not correct in its orographical features, their changes of the British Admiralty Chart (which they complain of) being much for the worse. They are incorrect also in assigning the limestone mountain masses of the north of Ægina to the Tertiary rather than to the Cretaceous period. Neumann and Pertsch[3] devote some space to this region, but their account is entirely taken from the three preceding writers, as is the case with Philippson,[4] whose field of study did not include Ægina, and who did not visit Methana.

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[1] Les Anciens Volcans de la Grèce. Revue des deux Mondes, LVIII., 1867, 470. Also cf. C. R. LXII., 904, 1121.

[2] Ausflug nach Ægina und Methana. Heidelberg, 1867, 84 pp. Ref. in Neu. Jahrb., 1868, 212.

[3] Phys. Geogr. v. Griechenland. Breslau, 1885.

[4] Der Peloponnes. Berlin, 1892.

GENERAL DESCRIPTION.

Ægina.—This island, whose culminating point, the summit of Mt. Oros, lies in Lon. 23°30′ E., and Lat. 37°42′ N., has almost the shape of an equilateral triangle, the north coast running east and west. The length of each of the sides is about 13 kilometres, and the total area about 85 sq. kilometres. The view presented by the island from the sea is striking, the dark gray bare slopes rising steeply from the low northern shore to the central heights, which in turn are joined by a fine curve with the sharp dominant peak of Mt. Oros, the last falling away in a long regular slope to the sea at Cape Pyrgos. The chief port and only town, likewise called Ægina, lies near the northern end of the western shore, the small harbor, formed by two jetties, being crowded with the gaily painted feluccas and other craft of the sponge fishers. It is a picturesque, prosperous little town of some 2500 inhabitants, one of the chief seats of the sponge fisheries of the Ægean Sea, and the centre of quite an extensive native trade in pottery, the Ægina jugs and vases being highly esteemed throughout Greece.

Geologically the island is divisible into five distinct districts, the first being the low fringing shore land on the north and northwest, the latest in point of geological time. The second is the mountainous region of the north and northeast, made up of Mts. Kokkalaki, Baro, the Temple Ridge, and Mt. Paliango, which are all of hard crystalline limestone of undoubted Cretaceous age. The next district is that comprising Mts. Stavro, Palæochora, and Spasmeno Vouno, and may be called for convenience the Stavro District. It is entirely composed of eruptive material, the characteristic rock being a light gray hornblende-andesite. The fourth district is the most complex, both topographically and lithologically. It embraces the ridges of Mts. Chondos, Dendros, Pagoni and Gaiapha, with some outlying spurs, as well as perhaps the north and south running line of hills called Mt. Kourágio. This district, which includes all the central part of the island, may be called the Monastery District (from the Monastery of the Panagia or Virgin in the centre). Lithologically it is chiefly characterized by the abundance of hornblende-augite-andesite. The fifth and last district, made up of Mt. Oros and its outliers, and to be known as the Oros District, occupies the whole southern angle of the island. Orographically, the subordination of the outlying members to a main central mass is much more clearly marked here than in the other cases. The main rock mass is an augite-hypersthene-andesite with later eruptions of dacite.

It may be mentioned here that neither on Ægina nor on Methana did I meet with any dikes, sheets, or other such intrusive bodies: the bearing of which point on the eruptive character of the region will be discussed later.

The north and northwest shores are low and flat, rising very gradually to the foot of the east and west running mountain range. This shore land, which is of late Tertiary age, is composed of horizontal beds of marl and a soft cream-colored limestone, such as is known throughout Greece as "Poros Stone" (πώρινος Λίθος), which is extensively used for building purposes, being soft and easily cut when first quarried, but hardening considerably on exposure. Along the north coast these beds give place to a breccia of limestone blocks cemented by a soft calcareous cement, which occupies the foot of the mountain range just mentioned.

This range, which belongs to the second district, embraces the mountains of Kokkalaki, Baro (199 m.), and the ridge (191 m.) on which stand the well-known ruins of the ancient Greek temple of Athena. These mountains are carved out of nearly horizontal beds of the gray or yellowish crystalline Cretaceous limestone (containing rudistes) which forms such a prominent geological feature of this part of the Balkan peninsula. The southern side of Mts. Kokkalaki and Baro is quite steep, the lower part being in places almost perpendicular—evidently an old shore cliff, the lower part of which is now invisible. On the south slope of Mt. Baro there crops out a horizontal stratum of dark red shale, and a similar, though smaller outcrop is seen near the west end of Mt. Kokkalaki. (Cf. Fiedler, I., 273.)

The limestone is continued to the southeast, as far as Mt. Paliango, forming horizontal beds, in places one or two metres thick, overlying clays. The small hill on which stands the chapel of St. Dimitrios is formed of beds of this same clay, capped by a thick bed of limestone, and not, as Fiedler says,[1] of reddish trachyte. The lower slopes of the Temple Ridge are covered with an andesitic breccia, similar to that described below, the andesite probably being derived from hills to the northeast, east, and south, which lack of time forbade my visiting, but which had the appearance of being andesite and not limestone. A ready means of discrimination is furnished by the small pine trees, which seem to grow best on a limestone soil. Both in Ægina and Methana the limestone mountains are either covered or plentifully overgrown with the common small Aleppo pine (*Pinus Halepensis*), while the mountains of eruptive material are almost, if not quite, devoid of them. The soft late Tertiary limestone is met with below the temple on the road to the Bay of St. Marina. To the southwest rises the long ridge of Mt. Paliango (or Paraliago), 292 m. above the sea, built up of gray limestone beds, dipping 15° to the southwest. The top is covered with pines, but the sides are steep and rugged, and the lower slopes covered with talus.

With the exception of some small alluvial and beach deposits, the rest of the island is of eruptive origin. These Cretaceous limestone masses must have formed, prior to the eruptions, a small island group, the presence of the breccia of water-worn andesite blocks, and late Tertiary beds of marl, etc., showing that elevation has since taken place. The surrounding smaller islands, Augistri, Moni, Metofi, Lagosa, etc., are to all appearances, made of the same hard Cretaceous limestone.

As we approach, coming from Ægina, the mountains south of the northern limestone ridge we find the Neogene limestone and marls gradually giving place to a coarse breccia of rounded blocks of andesite cemented by a soft white limestone of Tertiary age. These blocks, which vary in dimensions from the size of one's fist to larger than one's head, are of the same rock as that which forms the neighboring mountains, and seem to represent in part an ancient talus, worn by the action of the sea and subsequently cemented by the travertine-like material which partially forms the shore deposits. This sort of breccia is to be found up to heights of 200 metres.[1]

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[1] Op. cit. I., 274.

The most northerly mass of eruptive rock is that of the Stavro District, including the domes of Mts. Stavro (311 m.), Palæochora, and Spasmeno Vouno, and much of the lowest slopes of these is formed of the breccia just described. Mt. Stavro (Cross Mt.), which is formed of a compact mass of hornblende-andesite, presents some interesting peculiarities of structure. As we pass along the west side of the valley, between it and Palæochora we see that its east face, which is very steep above but more sloping below, is cut here and there by vertical joints running east and west. In one place two of these parallel joints are only four metres apart, and the intervening mass has slipped down some two metres, giving rise to slickensides on the two faces of the adjoining rock. The side walls show a columnar structure perpendicular to the vertical face. This columnar structure is very well developed around the whole east and north sides of Mt. Stavro, the irregular columns varying from 15 to 50 cm. in diameter, and on the northeast side dipping towards the southwest. They are cut by many transverse, but not decidedly "ball and socket" joints, one effect being that the east slope of the mountain is quite free from débris, while the north and northeast sides have their lower slopes thickly covered with a talus of angular fragments broken off from the columns above. The columns are often curved, and in some places a sub-spherical structure is developed. The upper part of the north face of the mountain is quite vertical, and shows a peculiar structure which, as it seems rather out of the ordinary, may be briefly described. Two straight vertical joints, running north and south, cut the rock face, and on each side of both of these is a secondary system of curved joints which meet the vertical joints at angles of 45° to 60°, curving downwards and approaching a vertical direction as they recede from the latter. These oblique columns are divided transversely by a tertiary joint system, cutting them about at right angles to their direction. The effect of these three systems of cracks is to give to the rock mass a "feather-like" columnar structure. As one goes farther to the northwest along this cliff the andesite is seen to be more and more disintegrated, till finally it becomes a pulverulent andesitic mass, resembling tufa, forming a low saddle running toward the limestone of Mt. Kokkalaki. The south slope of the eastern part of Mt. Kokkalaki is flanked by a mass of gray andesite, like that of the "feathered" cliff. Though covered with vineyards, it has the appearance of being a lava stream which flowed from the Stavro Centre and was hemmed in by the limestone ridge on the north.

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[1] B. & V., 258, R. & S., 15.

The hill of Palæochora (Ancient Village), about 300 m. above the sea, is a striking feature of the landscape; rather conical in shape, with slopes of about 30°, it is covered with the ruins of an old town dating from about the end of the sixteenth century, which was built during the period of Turkish occupation as an inland refuge from the numerous pirates that then infested these seas.[1] It is a picture of desolation; the old house walls, built of the gray andesite, still standing though roofless, and interspersed among the houses are numerous chapels, the largest of which, that of St. Cyriacus, containing some interesting frescoes, is still in use. The lower part of this hill is mainly an andesite conglomerate, but the upper part is compact andesite, though cracked and split into a roughly columnar structure.

Immediately to the southeast of this hill, partly resting on its flank, is one of the most remarkable geological features of the island, the so-called Spasmeno Vouno (Broken Mountain). This is a volcanic dome 300 to 400 m. in diameter, and rising from 50 to 60 m. above the valley to the south of it, which was originally well-shaped, of an almost hemispherical form, with gently curving sides, whose average slope varies from 20° to 30°. It is entirely composed of a coarse breccia of light hornblende-andesite, somewhat similar to that of Mt. Stavro, in large angular blocks, with a cement of small pieces and paste of the same material; the whole being rather soft, considerably weathered, and showing no signs of stratification. Many of the blocks show the peculiar sub-vitreous lustre which seems to be characteristic of lava when cracked and broken while cooling from a highly heated condition. The original dome is now to a great extent destroyed, the sides being cut by cracks and deep ravines with precipitous sides, the largest of these running quite across the hill from north to south, while the interior is quite hollow, forming a sort of amphitheatre with precipitous walls of rock. This amphitheatre is a scene of wild beauty, pinnacles and buttresses rising on all sides to heights of six to twenty metres, those towards the south being the highest. Two cases of faulting were seen, the throw being vertically downwards and the slip in one case being a couple of metres. Fiedler[1] apparently attributes the condition of the dome largely to explosive agencies, as he calls it "eine zerborstene Felskuppe." Judging from two examinations of the place, this explanation does not appear to me to be the correct one. For one thing, the surface of the dome and the surrounding ground are quite free from large blocks such as could naturally be expected to have been dropped there by an explosion. Again, the presence of tall slender pinnacles of the not very coherent breccia is quite incompatible with such an explanation. Spasmeno Vouno must be regarded then as a volcanic dome, formed by the outpouring of a partially solidified lava stream, the interstices between the blocks being filled chiefly by more liquid matter or by disintegration of the upper part. The mass cracked on cooling, such as we see a similar andesitic mass to have done at Stavro and Palæochora, and the fissures thus formed served as starting points for subaërial erosion. That this erosion is still going on here at quite a rapid rate is shown by the presence of a niche for the reception of a votive tablet, such as are very frequently met with in Greece, near the top of a slender buttress near the north side of the amphitheatre. This niche, which must date from Hellenic times, is now quite inaccessible. Much of the eroded material is now to be seen forming a terrace to the south and southwest of the dome, probably the "*sol bombé*" of the French geologists.[1] The deeper erosion of the southern part is explained by the fact that Spasmeno Vouno is formed on the southeast flank of the more compact Palæochora dome, the easily eroded mass of the later outflow being hence deeper toward the south.

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[1] Lacroix. Iles de la Grèce. Paris, 1881. p. 513.

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[1] Op. cit., I., 274.

The central part of the island is separated sharply from the districts just described by a straight, rather broad valley running about east and west almost across the island, at the bottom of which there flows during the wet season a small stream. In its western part the lower part of this valley is cut in the light hornblende-andesite breccia, while further east it is in limestone. This central part of Ægina—the Monastery District—is chiefly composed of two parallel ridges, having a trend of about North 60° West. The most northerly, called (at least its western half) Mt. Chondos (Near Mountain), runs almost clear across the island, ending at the east in Cape Peninda. Its sides are steep (over 30°) and the upper parts bare and rocky, while the lower slopes are often devoted to vines. As seen from the map the lower part of the north slope is composed of a hornblende-andesite like that of Stavro, while the rest of the ridge is chiefly composed of a compact hornblende-augite-andesite. The relation of the two could not be clearly made out in my somewhat hurried trips, but it seemed probable in places that the former rock overlies the latter. On the north side, near the west end and opposite Mt. Stavro, are beds of gray, pulverulent, fine-grained tuff which overlie the fringing andesite breccia. The dip of these beds varies, in one place being 30° southeast, while in another they are horizontal. A bed of compact brown rock which seems to be silicified tuff is also found farther east near the crest of the ridge, and according to Reiss and Stübel[2] a tuff occurs near the base of the east end, south of Mt. Paliango. A little west of north of the Monastery the ridge of Mt. Chondos is made up of rounded masses of andesite which split up into more or less perfect concentric shells on hammering (perhaps an effect of weathering[1]), and which are cemented by a paste of the same material. Almost due north of the Monastery the top of the ridge has quite the appearance of a lava stream of the type that one sees at Giorgio Kaimeni in Santorini, being composed of sharp, angular blocks tumbled together in great confusion.

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[1] B. & V., 254.

[2] R. & S., p. 17.

The southern ridge, called Mt. Dendros (Tree Mountain) is much shorter, ending at the east in a peak on which stands another chapel to St. Dimitrios. It then bends round to the southeast, enclosing, with Mt. Chondos, a small fertile plain in the northwest corner of which stands the Monastery of the Panagia (Holy Virgin). This plain, which is roughly triangular in shape, is bounded on the east by a ridge which bears the name of Mt. Kourágio, to be described presently. The plain is drained by a stream flowing through a deep valley in its northwest angle. Although at first glance it looks as if this Monastery plain were the site of an ancient crater, yet closer examination of the region fails to confirm this impression.

The branch of Mt. Dendros which bounds the plain on the south is called Mt. Gaiapha and has a height above sea level estimated at 500 metres. The inner (north) side of this is very steep, a mound of talus below and steep cliffs above, the rock being split by vertical cracks running southwest and northeast. The rock is a light reddish hornblende-augite-andesite carrying many of the segregations to be described later. It weathers very easily and is hollowed on the northern face into caves and pockets, some of which are two metres across. The southern slopes are covered with angular blocks and overgrown with grass, thyme, and scrub-oak.

The ridge which bounds the Monastery plain on the east bears the name of Mt. Kourágio, though here as in so many other places the mountain peaks and ridges do not possess very definite names and are often called by different names by different inhabitants. The sides are steep and covered with large angular blocks of a compact dark pyroxene-andesite, almost identical with that of Mt. Oros. So great is the similarity that petrographically it belongs to the latter district, while topographically it should be placed in the Monastery district, as it terminates sharply and steeply at its southern end on the 250-metre high saddle connecting the central Monastery district with Mt. Oros. Besides the mountains just described there are a number of subordinate spurs and ridges which belong to this district, such as Mt. Pagoni (Peacock Mountain) and the dacitic ridge near St. Vasili on the west coast.

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[1] Cf. REYER, Die Enganeen, Wien, 1877, p. 20.

The southern part of the island is connected with the district just described by the above-mentioned saddle which is flanked by two valleys running respectively west and east. This angle of Ægina is occupied by the dominating mass of Mt. Oros, 540 metres high, with its outlying spurs. This mountain is of quite regular conical shape, near the top the sides sloping at angles of about 35°, and at the south running down to the sea in a long slope of about 15°. The area at the summit of the mountain is not large, and chiefly taken up by a small chapel of St. Elias, this uppermost platform being bounded on the south by steep, but not high declivities. No indications of a crater were to be noted, and the topmost rock is a fine-grained, dark gray pyroxene-andesite, with a quite well developed, phonolite-like system of joints, the rock splitting easily into thin slabs. This structure is also met with in the augite-andesite of St. Somatos on the north-east foot, where are some well-preserved Hellenic walls. The flanks of the mountain are covered with angular blocks, making the ascent and descent very fatiguing. As seen from the map the lowest slopes of the mountain are made up of radiating ridges, most of which seem to be due to erosion, while some may be of the nature of lava streams. A small eruptive dome exists on the east flank near the hamlet of Anzeiou, forming a hill 297 metres high. This is formed of a compact dark hornblende dacite, as is the hill of Kakoperato, another later flank eruptive centre, on the northwest flank near the shore.

Methana.—The promontory of Methana, also called in antiquity Methōnē, lying about 7.5 km. southwest of Ægina, is almost an island, being joined to the mainland by an isthmus barely 0.3 km. wide. Its otherwise almost circular outline is broken on the northwest by the projection formed by the hill of the Panagia, a mass of gray Cretaceous limestone, 210 metres high, and on the south by a similar limestone mass, of which the isthmus is a prolongation. Its shores in general are rocky, though beaches occur in places. The general appearance is extremely rugged and forbidding, the rocky slopes coming down to the water's edge at angles of 25° to 35°, and the whole promontory being a confused agglomeration of bare peaks rising gradually but irregularly to the not very prominent mass of Mt. Chelona in the centre. This exterior impression is heightened on closer examination, arable land being very scarce and the few and poor inhabitants wringing a scanty subsistence out of the stony slopes.

The chief harbor and village is on the southeast coast at Vromo Limni (Stench Harbor), so called on account of the hot sulphur springs (temperature 27° C.), where there is a summer bathing establishment—the only place where tolerable accommodations can be secured. Hot sulphur springs also exist on the northeast coast near Agios Giorgios. Near the shore, on the southwest, are the small walled acropolis and other scanty remains of the ancient Greek capital of the district, which for the sake of clearness will be referred to as Methone, its ancient name, the modern village of Megalo Chorio (Large Village), being perched on the mountain slopes above. The other villages are merely clusters of wretched houses.

Geologically the promontory is simpler than Ægina. The Neogene limestone formation, including the flanking breccias, is wanting, which may be partially explained by the fact that Methana lies in an area of subsidence. Cold[1] has shown that the east coast of the Peloponnesos from Cape Matapan to Hermione has subsided in historical times, and as my guide described columns and ruins lying beneath the sea near Methone, it seems

[1] COLD: Küsten Veränderungen im Archipel. München, 1886, p. 14 and map.

that this line of subsidence must be extended farther north to Methana. We find, as already noted, the same gray Cretaceous limestone as in Ægina, at Mt. Panagia and at the southern end near the isthmus. The junction of this with the eruptive rock in the former place is quite sharp though obscured by talus, but I could find no traces of the metamorphic action of the lava on the limestone which Fiedler describes. The junction on the south is covered by a broad, shallow alluvial valley devoted to cultivation.

The rest of Methana is entirely composed of eruptive material, and, while apparently simpler and not divisible into districts, is less clean cut and well defined in its orographical features than is the case on Ægina. The highest point is the summit of Mt. Chelona (760.7 m.) in the centre, which, however, hardly overtops several of the surrounding peaks. The summit is formed of a ridge of huge angular fragments of rock running east and west. This rock is a hypersthene-andesite, dark gray in color, and very compact and fine grained, though several fragments show a coarse scoriaceous structure, which was probably the reason why the English officers labeled the peak "extinct volcano" on the chart. The same rock is found at Methone and at Megalo Chorio, and, though the stratigraphical relations were difficult to make out in the short time at my disposal, this mass of rock seems to be older than the surrounding masses of dacite.

On the south, Mt. Chelona is separated from the mountain above Vromo by a broad valley which runs down to the small Vathy (Deep) Harbor on the west coast. The topmost ridge, just spoken of, forms the southern boundary of a small plain in which are the remains of a "bee-hive" tomb similar to those at Mycenæ and elsewhere. This plain slopes down to a long valley on the north which separates Mt. Chelona from several peaks almost as high as itself, on one of which are the ruins of an old castle and town as at Palæochora on Ægina, and also bearing the same name. To the east lie several peaks, and in passing from the summit down to Kosona on the east coast one crosses a level plain of some size and almost circular shape, surrounded by high hills.[1] It has not, however, the appearance of a crater. In the centre of this is a low, flat, circular rocky eminence, about 10 m. high by 80 m. in diameter, composed of a much decomposed pulverulent eruptive rock, originally probably a dacite, carrying many small rounded segregations. Here we have undoubtedly a late centre of eruption. The ridge separating this plain from the sea on the east is covered with large angular blocks of dacite, while the slope below is composed of a dacitic breccia, the cement being a fine-grained tuff-like paste of the same materials.

There remains to be described one more locality which, for several reasons, offers the most important and interesting features of any on the peninsula. This is the hill lying on the northwest coast, east of the limestone of Panagia, called Kaimeni (Burnt); here we have the seat of the most recent eruption of the whole Ægina-Methana region.

The Kaimeni is a ridge about two km. long running northwest from near the hamlet of the same name, forming a promontory in the sea. Its highest point is 416.9 metres above sea level and 206 metres above the small valley at its southern end.[2] Its flanks, which have a slope of 37°, are composed of large and small angular blocks of andesite with some scoria, the latter being especially abundant near the bottom of the southwest flank. At the top is an oval depression, 60 to 80 metres deep and measuring perhaps 100 by 150 metres, its long axis lying parallel with the crest of the ridge. The walls of this depression are very steep, in many places perpendicular, of large blocks of rock or solid cliffs split in places by wide cracks, some of these being fifteen metres deep. The bottom is covered with angular fragments of andesite. This hollow is undoubtedly an explosion crater, but the character of the eruption need not be discussed here. Beyond this crateral cavity the lava stream runs to the northwest projecting into the sea. This seaward part of the stream is quite distinct from that just described, being brown and apparently scoriaceous, and weathered into tall pinnacles rendering it almost inaccessible.

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[1] This is not the circular "crater-like" plain described by Reiss and Stübel (p. 34), which lies to the northwest of Chelona, and whose crateriform character did not strike me, though I passed through it.

[2] R. & S., pp. 24.

This Kaimeni is undoubtedly the site of the last and only historical eruption of the whole region, which occurred during the reign of Antigonus Gonatas, King of Macedonia, 227–239 B. C., and which has been spoken of by Strabo, Pausanias, and Ovid. Pausanias[1] is very brief and merely speaks of hot springs, 20 stadia (2.5 miles) from the small city of Methana, which started during the reign of Antigonus, the water not appearing first, but being preceded by an eruption of fire from the ground. Strabo's[2] account is more explicit and runs as follows: "Near Methone, which is on the Hermionic Gulf, a mountain seven stadia high was cast up during a fiery eruption. During the day it could not be approached on account of the heat and the sulphurous smell, but by night it emitted an agreeable odor and appeared brilliant at a distance; the heat was so great that the water of the sea boiled for five stadia around and was turbid at a distance of twenty stadia. On the hill were found masses of rock as large as towers." Ovid[3] is much more fanciful, and he describes poetically how the winds enclosed in interior cavities, seeking an outlet, finally elevated a mass of rock like a bubble, which was still standing in his day. This poetical description has been brought forward by Humboldt and others in support of von Buch's theory of craters of elevation.[4]

The identification of the site of this historical eruption, which as we have seen is due to Fouqué, is of great importance for many reasons. In the first place it shows us the character of at least one eruption of the region with clearness and certainty. It also, by the state of preservation at the end of the two thousand years which have elapsed since the eruption, furnishes a measure of comparison for the other eruptive centres, and it also gives

[1] PAUSANIAS, II., 34. 1.

[2] STRABO, I., 3. 18.

[3] OVID: Metamorph., XV., 296–306.

[4] Cf. DAUBENY: Volcanoes, London, 1848, p. 327.

us specimens of what we know to be definitely the latest products of eruption.

The fact of an eruption having taken place here in historical times raises the question whether the volcanic forces of the region are extinct, or merely dormant. The hot springs of Methana and probably the mofetti of Sousaki are apparently the last visible signs of volcanic activity, and it seems almost certain that the volcanic forces of Ægina and Methana are quite extinct. But on the other hand, when we recall the long periods of absolute repose that we know to have lasted in some cases between two volcanic eruptions, as that of about seventeen centuries at Ischia, we cannot feel absolutely sure that some time the dormant forces will not be roused, and that we shall not have a fresh chapter to add to the vulcanological history of Methana.

Poros.—The only part of this island (which lies immediately to the southeast of Methana) which is of interest in the present connection is the small promontory on the south coast on which the town of Poros stands, connected with the main part of the island (composed chiefly of Cretaceous slates and limestones) by a low sandy isthmus. This small peninsula is a bare rocky hill, a mass of gray and reddish hornblende-andesite, the difference between the two colors being due only to weathering, as Philippson[1] has pointed out. No traces of a crater are to be seen, and the hill is evidently due to an eruption of the domal type which probably took place in the Quaternary period.[2] Some well-stratified tuff beds, with a dip about 20° to the north, are to be seen near the shore in the town.

Kolautziki.—As my examination of the occurrences of eruptive rock on the mainland of Greece was confined to collecting at the railroad cutting west of the small village of Kolautziki I shall draw largely on Philippson's description.[3] Near Kalamaki, which is on the east side of the Isthmus of Corinth, there is found an eruptive rock which Philippson calls a quartz-trachyte, but which, judging from the specimens collected farther east is probably more correctly to be called a dacite. The range of hills (chiefly of late Tertiary marls and conglomerates) in which this rock is found runs east parallel with the north shore of the Saronic Gulf and only a few kilometres distant from it. In these hills is the valley of Sousaki[1] with its mofetti. The rocks of this valley are of serpentine and less altered gabbro, and Reiss and Stübel are inclined to attribute the emanation of CO_2 and the other phenomena of the mofetti, not to volcanic agencies, but to the decomposition of the gabbro. Philippson combats this view, and I think correctly, though this is not the place to enter into discussion of the matter. Southeast of this, between the range of hills and the sea, is a low hill land, which is mostly "quartz-trachyte" with marl and conglomerate of late Tertiary and Quaternary age. A little to the west of the hamlet of Kolautziki, nine kilometres east of Kalamaki, the railroad cuts through a mass of this dacite, the width of the cut being 112 metres. This mass of eruptive rock is in general solid and compact, though in places made up of a coarse breccia cemented by finer material of the same nature. No scoriæ was to be seen. As Philippson says, it seems to be the end of a lava stream flowing from the west, though he was unable to find its place of origin. This stream is overlaid by late Tertiary limestone, and hence belongs to the same period as the earlier outflows of Ægina and Methana

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[1] Op. cit., p. 46.

[2] PHILIPPSON: op. cit., p. 433.

[3] Op. cit., pp. 21 ff.

CHARACTER AND DATE OF ERUPTIONS.

Before passing on to the petrographical description of the various rocks some space must be devoted to the conclusions that may be drawn from the facts observed by myself and others in regard to the character of the eruptions which formed the masses of Ægina and Methana, their geological date, and the order in which the various rocks were poured out.

In taking up the question of the character of the eruptions we shall start from the most definitely known and least denuded focus, that of the Kaimeni on Methana. Here we have an example of that type of eruption so happily called by Fouqué[1] "cumulo volcanoes." The type specimen of this class of volcanoes is the cone of Giorgio Kaimeni in Santorini, produced by the great eruption which began in February, 1866, and whose formation was closely watched and studied by scientific observers from the beginning to the end.[2] The succession and character of the phenomena in this eruption were briefly as follows: The eruption began as a submarine outpouring of lava and lava blocks, accompanied by few or no explosions. As the mass reached the surface of the sea it was seen that the outflow consisted of a stream of solid angular lava blocks, pouring out slowly and with no explosions till they gradually heaped themselves above sea level, forming a "cone" quite different from any of the well-known types, there being no crater, no stratification of any kind, no tuff, scoriæ, nor ashes, and no flow of liquid lava. It was simply the quiet exudation of a mass of solid angular blocks of eruptive rock, whose rate of progress was slow, not forming streams such as liquid lava forms, but a comparatively short and high agglomeration of loose blocks. Such a cone is also quite different from the also craterless typical *Kuppen* of the Rhine, *puys* of Auvergne or *mamelons* of the Island of Réunion, which are due to the exudation of liquid but pasty material.

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[1] For descriptions of this interesting and little visited locality cf. Philippson, op. cit., p. 22, and the references there given.

A suggestion put forward by Professor J. D. Dana[3] in regard to certain lava streams of Mauna Loa and Kilauea, offers a good explanation of the structure just described. The lava streams called in Hawaii *aa*, are likewise composed of loose angular blocks, and Dana suggests that this structure is due to the lava stream flowing over a region containing subterranean moisture in quantity sufficient to cool and fracture the lava and not be evaporated by the first hot portions of the stream.[4] In the case of the first submarine outpourings at any considerable depth the conditions must be quite different, partly owing to the important factor of the great pressure here involved. But when the lava mass has reached nearly to, or a short distance above, the surface of the sea we get a condition of affairs similar to that suggested by Dana, resulting in the cooling and cracking of the lava stream into solid blocks which are forced upward and onward by the outpouring stream below, forming a cumulo volcano. That there are few or no explosions during this phase of such a submarine volcano may be accounted for by the action of the sea water in cooling and condensing a large part of the imprisoned water vapor, as well as by the presence of the numerous cracks in the mass, serving as so many vents for its outlet.

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[1] FOUQUÉ: Santorin, Paris, 1879, p. xv.

[2] Cf. FOUQUÉ: Santorin, Cap. II.

[3] DANA: Characteristics of Volcanoes. New York, 1890, p. 243.

[4] I have observed such an action in the glass works at Murano, where a large mass of molten glass was poured into water, with the result that it was cracked into large pieces, much resembling the lava blocks of Giorgio Kaimeni.

"Stone streams"[1] due to such a cause differ radically from the ordinary lava streams made up of loose blocks, such as one meets with on Vesuvius or Etna, which are due to a simple mechanical breaking up of the solidified scoriaceous crust by the movement of the mass and the frequent subsequent flowing away of the liquid material.

The eruption may cease at this stage, as at the May Islands in Santorini; or when a certain quantity of lava blocks has been extruded, their mass and height above water varying with the special conditions, the character of the eruption may change, as at Giorgio Kaimeni, to the ordinary type, a crater being formed and explosive ejections of ashes and lapilli, or the pouring out of liquid lava, following.

Now, to return to the Kaimeni of Methana, whoever has seen the two volcanic masses produced by the eruptions of 1866 at Santorini and *ca.* 250 B. C., at Methana, cannot doubt for an instant that the earlier eruption was of the same type as the later. We find at Methana the same short high stream composed of a wild confusion of angular lava blocks, with little scoria. There is also a crater hollow at Methana, which however differs from that at Giorgio Kaimeni[2] in being deeper and with more precipitous walls, pointing to the fact that at the former place the eruption ceased with the explosion which produced the crater; a conclusion strengthened by the absence of ashes and lapilli, with which the crater and the upper part of the cone of Giorgio Kaimeni are covered.

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[1] JUNGHUHN: Java, II., p. 762.

[2] For plan of this crater cf. Fouqué: Santorin., Pl. XXX. and Ann. d. Sc. Géol., VII., Pl. 7.

Such then may be taken as the mode of formation of the earliest and lowest portions of the two areas. As Reiss and Stübel have so well described,[1] we must consider the first eruptions to have formed a cluster of small islands in the sea near the preëxistent limestone islands, such as we find in the analogous case of Santorini at the small Kaimeni Islands in the centre of the bay. These earliest submarine eruptions and some of the later ones took place either just before, or more probably during, the later Tertiary period,[2] as is shown by the andesitic breccias cemented by Neogene limestone.

The analogy between Santorini and our region, however, ceases with the formation of the smaller cumulo volcanoes, for at the former place a large, thoroughly typical strato-volcano was formed, while in the latter the later eruptions seem to have belonged to a different type. These later eruptions were chiefly subaërial and were continued into the following geological period, and even, on Methana, into historical times. They were nearly all eruptions of the dome (*Kuppe*) type—the exudation of large masses of pasty material, accompanied by few explosions and with little formation of tuff or scoriæ, forming high steep mountains or short thick streams. These eruptions did not take place at one centre, but at various points of the region and along fissures forming the complex of hills and mountains that we now see.

That the main mass of both Ægina and Methana is made up of such a complex of volcanic domes, and is not the denuded wreck of a strato-volcano is clearly shown by the following facts: The chief of these is the absence of inter-stratified beds of lava and tuff, and of lava sheets, such as form the chief characteristic of strato-volcanoes, built up of explosive ejection of fragmentary material and the pouring out of liquid lava streams, of which Vesuvius and Etna are taken as types. Tuff exists, it is true, in some places on Ægina, as we have seen, but here it exists on the surface, overlying the massive rock at the flanks of the mountain, and it is well known that such deposits do accompany volcanic domes. Lava sheets are, however, quite lacking. It is evident from an examination of the region that the denudation has not been very extensive, so that the absence of tuff cannot be explained on this ground; any amount of which, moreover, would not explain the absence of inter-stratified tuff beds and lava sheets. The denudation has not been nearly as extensive as that which has taken place in the somewhat similarly formed Euganean Hills near Padua in Northern Italy, where the eruptions ceased in post-Eocene time,[1] though it must be remarked that the climate is here more favorable to denudation than in our region. The main valleys between the mountain masses must hence be looked on as original intercolline spaces, enlarged, though slightly, by erosion.

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[1] R. & S., p. 39.

[2] Cf. Neumayr. Geol. Bau. d. Insel Kos., etc. Denkschr. d. K. Akad. d. Wiss., Vol. XL., 1880, p. 264; Philippson, Peloponnes., p. 433.

The forms of the mountain masses and their mutual positions are decidedly those to be looked for in the case of eruptions of the kind supposed, and different from those produced by the erosion of a strato-volcano. While not of the regular "bell" shape that is seen in such perfection in the "*puys*" of the Auvergnes or the "*mamelons*" of Réunion, yet the shape of the ridges is eminently such as would be produced by the extension of a mass of viscid lava (without the formation of explosion craters) at many points along a fissure, such as have been described by Scrope[2] and Hartung.[3] The masses are higher and shorter than those which would be formed by liquid lava streams, and they do not, except in the case of Mt. Oros, radiate from a common centre.

The character of the lavas also is eminently favorable to the

[1] REYER, Die Enganeen, Wien, 1877, p. 48.

[2] SCROPE, Volcanoes, 2nd ed., 1862, p. 134.

[3] HARTUNG, Beobacht. über Erhebungskrater, etc., Leipzig, 1872, p. 57.

production of domes. Being porphyritic andesites and dacites of medium to rather high acidity they were, when ejected, in a pasty rather than a very fluid condition,—the state of viscosity which is essential to the production of domes and masses of great height as compared with their lateral extensions.

Another fact in favor of the view here held is the total absence of dikes, which are rare in dome eruptions, but common and characteristic in those of the other type. This might, perhaps, be explained by the small amount of denudation, inasmuch as dikes, when present, are much more numerous and of larger size near the base than in the upper layers of volcanoes of whatever type.[1] Their *total* absence, however, cannot reasonably be so explained and, taken in connection with the facts above mentioned, must be regarded as a confirmation of the present view. It may be added that the columnar structure of Mt. Stavro and the laminated structure of Mts. Oros and Chondos, which are characteristic of *Kuppen*, point in the same direction.

It is probable, however, that in some places, streams of more liquid lava were poured out, as east of Mt. Stavro, and perhaps in some of the ridges to the south and east of Mt. Oros, which I was unable to examine. As has already been suggested, there also may have been true craters on Methana, though it does not appear probable to me. These, however, would be secondary phenomena, and we must regard it as certain that the great majority of the eruptions which formed the two regions were of the dome type, as defined by von Lubach,[2] based on a substructure of cumulo-volcanoes, which have also been formed in some of the later flanking secondary eruptions.[3]

Relative age of the various lavas.—It has already been briefly noted, and we shall see at greater length later on, that lavas of quite diverse chemical and mineralogical composition were erupted at different points of the region under examination, and it is an important matter to ascertain the relative age of these various outflows. To this problem, unfortunately, I can not furnish a very satisfactory or absolutely certain solution, owing to reasons already spoken of and to the scarcity of good exposures and sections; so that the following remarks merely indicate what I believe (though on slight evidence) to be the true state of affairs. I may express the hope that some future observer will decide the question definitely.

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[1] Cf. GEIKIE, Text-Book of Geology, 1893, p. 233.

[2] Z. d. d. Geol., Gesell. XVIII., 644.

[3] It is noteworthy that the eruptions of andesites, very similar to those described in this paper, which occurred at Milos (according to Ehrenberg) and at Smyrna, Sipylos and Pergamon (according to my own observations) were all decidedly of the domal type.

In the case of Ægina it is probable that the eruptive activity shifted, as a whole, from south to north. That is, the Oros district is the oldest, followed by the formation of the masses of the Monastery district, and that last of all the hornblende-andesites of the Stavro district were ejected, the formation of Spasmeno Vouno closing the period of eruptive activity on Ægina. This is the general plan, but it is very likely that some of the smaller eruptions, such as those of Anzeiou or Kakoperato, took place during periods when, or between which, the main eruptions of another district were taking place, a fact frequently observed in volcanic regions.

In Methana the sequence of events is less clear than on Ægina, but from analogy with the Ægina rocks and for other reasons, I am inclined to believe that the main andesitic mass of Mt. Chelona was first formed, and that the peaks surrounding it were subsequently ejected. On chemical grounds, which will be discussed on a later page, it seems probable that Methana is, on the whole, younger and more recently formed than Ægina.

HENRY S. WASHINGTON.

(To be continued.)